DEVELOPMENT OF LOW-COST AQUAPONIC SYSTEM USING MEDIA-FILLED SYSTEM (MFS), DEEP-WATER RAFT SYSTEM (DWRS) AND NUTRIENT-FILM SYSTEM (NFS)

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Aquaponic system integrates aquaculture with hydroponics by stocking of aquaculture animals with aquatic plants in a closed recirculating system. Obviously, plants grow in a soilless environment, with fish waste supplying the nutrients needed for their growth. The biological filtration carried out by nitrifying bacteria neutralizes the toxic elements that would otherwise produce in the system from nitrogenous waste of stocked animals and render the same of use by the plants. This study utilizes the fundamental elements of this biodynamic system to develop three diversified systems, namely Media-filled system (MFS), Deep-water raft system (DWRS) and Nutrient-film system (NFS), and to examine their production efficiency. Observations were made on growth and survival of cultured Nile tilapia (*Oreochromis niloticus*) and green beans (*Phaseolus vulgaris*) together with chinese cabbage (*Brassica rapa chinensis*) in these systems. The results showed no significant differences (P>0.05) in fish performance in terms of weight gain, specific growth rate and feed conversion ratio and survival rate of nile tilapia in each of the treatment. Interestingly, significant differences (P<0.05) were noticed in biomass gain of green beans and chinese cabbage in different treatments. Nutrients concentrations in these three aquaponics systems ranged from 0.23 ± 0.02 mg/L to 0.29 ± 0.11 and 0.39 ± 0.22 mg/L to 0.61 ± 0.19 mg/L for NH_3-N and NO_2-N, respectively. These values showed no significant difference (P<0.05). However, significant differences (P<0.05) were seen in the concentrations of NO_3-N and PO_4-P which were in the range of: 0.89 ± 0.37 mg/L to 1.4 ± 0.39 mg/L (NO_3-N) and 0.45 ± 0.04 mg/L to 0.57 ± 0.2 mg/L (PO_4-P) indicated plants taken up nutrients of NO_3-N and PO_4-P to grow. The result also showed highest production efficiency is in the MFS; approximately 1 kilogram of green beans was produced where no significant difference (P>0.05) detected with DWRS, while, MFS and DWRS do have significant difference (P<0.05) with NFS. For Chinese cabbage productions, the biomass produced within the three systems were not achieved the marketable size. Then, the next experiment was the comparison between combined aquaponic system (MFS+DWRS) and single DWRS carried out to evaluate the growth performances of GIFT (genetically improved farmed tilapia) and tomato (*Solanum lycopersicum*) plant. It was revealed that the GIFT gained 94 % of body weight whereas height of tomato plant increased by 96.3 % and starting the flowering process (early stage of fruit formation) in the combined aquaponic system. The water quality parameters recorded throughout the study period were within the acceptable range for fish culture. The concentrations of NO_3-N and PO_4 were evidently adequate for plants to grow. The data leave no doubt on the effectiveness of combined aquaponic system compared to single DWRS. As a conclusion, the presence of aquaponic in the aquaculture system did not give any deleterious effect to fish growth performances. Wastewater within the aquaculture system was possible to become main source of nutrient for the plants that grow without the presence of soils. The developed aquaponic sub-systems were not only suitable for integrating system for biomass crop production, but also useful to reused nutrient rich water available in the aquaculture system.

ABSTRAK

PEMBANGUNAN AKUAPONIK KOS-RENDAH MENGGUNAKAN SISTEM MEDIA FILLED (MFS), SISTEM DEEP-WATER RAFT (DWRS) DAN SISTEM NUTRIENT-FILM (NFS)

Sistem akuaponik adalah gabungan daripada akuakultur (penternakan ikan) dan hidroponik (sistem tanaman yang menggunakan air sebagai media) dalam sistem akuakultur resirkulasi tertutup. Tapisan biologi oleh bakteria nitrifying meneutralkan unsur-unsur toksik kepada tidak bertoksik dan akan menghasilkan sisa-sisa nitrogenous yang akan digunakan oleh tumbuh-tumbuhan. Kajian ini menggunakan elemen asas sistem biodinamik untuk membangunkan tiga sistem iaitu Media-filled system (MFS), Deep-water raft system (DWRS) dan Nutrien-film system (NFS), dan untuk memeriksa kecekapan pengeluaran sistem-sistem tersebut. Pemerhatian telah dibuat pada pertumbuhan dan kemandirian hidup ikan Nile tilapia (Oreochromis niloticus) dan kacang buncis (Phaseolus vulgaris) bersama-sama dengan kubis cina (Brassica rapa chinensis) dalam sistem ini. Hasil kajian menunjukkan tidak terdapat perbezaan yang signifikan ($P>0.05$) dalam prestasi pertumbuhan ikan dari segi berat badan, kadar pertumbuhan spesifik dan nisbah penukaran makanan juga kadar hidup. Menariknya, perbezaan yang signifikan ($P<0.05$) telah dikenalpasti diantara biomas kacang hijau dan kubis Cina. Kepekatan nutrien dalam ketiga-tiga sistem aquaponic adalah di antara 0.23 ± 0.02 mg/L sehingga 0.29 ± 0.11 and 0.39 ± 0.22 mg/L sehingga 0.61 ± 0.19 mg/L untuk NH_3-N dan NO_2-N, masing-masing. Walau bagaimanapun, perbezaan yang signifikan ($P<0.05$) telah dilihat dalam kepekatan NO_3-N dan PO_4-P yang berada dalam lingkungan: 0.89 ± 0.37 mg/L sehingga 1.4 ± 0.39 mg/L (NO_3-N) dan 0.45 ± 0.04 mg/L sehingga 0.57 ± 0.2 mg/L (PO_4-P). Nilai-nilai ini menunjukkan perbezaan yang signifikan ($P<0.05$) menunjukkan bahawa tumbuhan mengambil nutrien NO_3-N and PO_4-P untuk membesar. Hasil kajian menunjukkan kecekapan pengeluaran tertinggi MFS adalah paling tinggi, secara anggaran nya ialah 1 kilogram untuk kacang buncis, yang mana MFS tidak mempunyai perbezaan signifikan ($P>0.05$) dengan DWRS. Manakala MFS dan DWRS mempunyai perbezaan signifikan ($P<0.05$) dengan NFS. Bagi kubis cina pula, pertumbuhan adalah tidak mencapai biomas kebolehpasaran dalam ketiga-tiga sistem akuaponik. Selepas itu, kajian kedua dilakukan untuk membuat perbandingan antara gabungan sistem akuaponik (MFS+DWRS) dan DWRS tunggal untuk menilai prestasi pertumbuhan GIFT (genetically improved farmed tilapia) dan tomato (Solanum lycopersicum) mendedahkan bahawa GIFT mendapat 94% daripada berat badan manakala tinggi pokok tomato meningkat dengan 96.3% dengan bermulanya proses pendebungaan (peringkat awal pembentukan buah) dalam sistem akuaponik gabungan. Parameter kualiti air dicatatkan sepanjang tempoh kajian berada dalam julat yang boleh diterima bagi ternakan ikan. Kepekatan NO_3-N dan PO_4-P adalah jelas mencukupi untuk tumbuh-tumbuhan untuk membesar. Data yang dihasilkan langsung tidak meragukan mengenai keberkesanan gabungan sistem akuaponik berbanding sistem tunggal DWRS. Sebagai kesimpulan, kehadiran sistem akuaponik di dalam sistem akuakultur tidak langsung mengganggu pertumbuhan ikan. Air sisa buangan daripada sistem akuakultur menjadi sumber utama nutrien untuk tumbesaran tumbuhan tanpa tanah. Sistem akuaponik sub-sistem yang telah dibangunkan bukan hanya sesuai menjadi integrasi pengeluaran hasil pertanian, tetapi juga sebagai nutrien yang boleh diguna semula di dalam sistem akuakultur.

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LIST OF ABBREVIATION

MFS	-	Media filled system
DWRS	-	Deep water raft system
NFS	-	Nutrient film system
kg	-	Kilogram
FAO	-	Food and Agriculture Organization
P	-	Phosphorus
N	-	Nitrogen
pH	-	Potential hydrogenii
DO	-	Dissolved oxygen
EC	-	Electrical conductivity
g	-	Gram
mg/L	-	Milligram per litre
NH_3-N	-	Ammonia-nitrogen
NO_2-N	-	Nitrite-nitrogen
NO_3-N	-	Nitrate-nitrogen
PO_4-P	-	Phosphate-phosphorus
UMS	-	Universiti Malaysia Sabah
RM	-	Ringgit Malaysia
S.E	-	Standard error
cm	-	Centimetre
et al.,	-	And others
USA	-	United State of America
ft	-	feet
gal	-	galloon

LIST OF SYMBOLS

%	-	Percent
°C	-	Degree celcius
<	-	Less than
>	-	More than

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The world population and nutritional demand are rapidly increasing. In the next 40 years, the human population would reach approximately 9 billion; requiring food in much larger quantity that world is struggling to produce even for the current population (Godfray *et. al*, 2010). The world would need at least 70 % to 100 % more food by 2050 to meet the demand (Garcia and Rosenberg, 2010). However, the target production set at the World Summit on Food Security is 44 million metric tons per year, representing 38 % over historical food production for at least 40 years ahead (Tester and Landridge, 2010). For the last five decades, fish production has been maintaining a progressive trend of annual rate of growth of 3.2 % (Figure 1.1) (FAO, 2014).

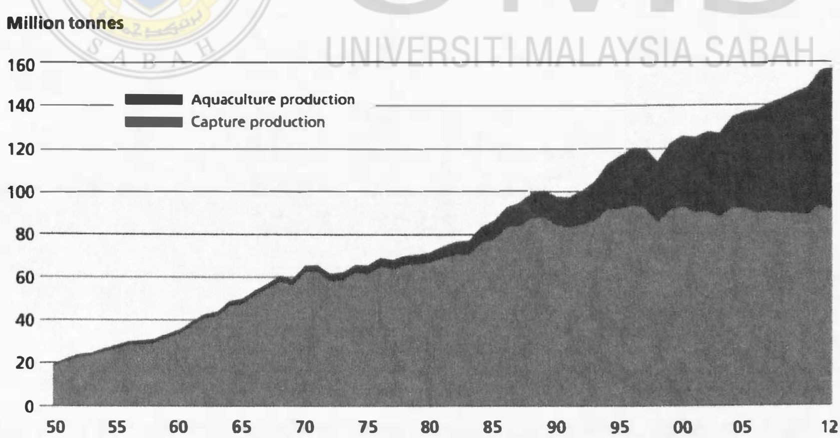

Figure 1.1: World Capture Fisheries and Aquaculture Production during 1950-2012

Source : FAO, 2014

Aquaculture production has grown steadily over the last 50 years while the capture fisheries have begun to decline due to over-exploitation and other factors. The stagnation of landings indicates that capture fisheries cannot meet the rising demand. World fisheries and aquaculture production and utilization (Table 1.1, Figure 1.2) is improved as factors by combination of great population growth; high source of income, urbanization, more efficient distribution, delivering fish to consumer, and strongly triggered by expansion of fish demand as world per capita of fish consumption increased from an average of 9.9 kg in 1960's to 19.2 kg in 2012 (FAO, 2014). The production from aquaculture is greatly needed to be increased while maintaining the ecosystem balance (Naylor *et al.*, 2000). In fact, the best hope of providing and meeting the future demand is likely to co-ordinated partnership and a significant increase in aquaculture production (Muir and Young, 1998). Aquaculture alone cannot meet the demand. We should not give up on capture fisheries management. The keywords to sustain fisheries are ecosystem approach to managing the harvest from the sea and integrated management of coastal zone (Tidwell and Allan, 2001).

Table 1.1: World Fisheries and Aquaculture Production and Utilization

	2007	2008	2009	2010	2011	2012
			(Million tonnes)			
PRODUCTION						
Capture:						
Inland	10.1	10.3	10.5	11.3	11.1	11.6
Marine	80.7	79.9	79.6	77.8	82.6	79.7
Total capture	90.8	90.1	90.1	89.1	93.7	91.3
Aquaculture:						
Inland	29.2	32.4	34.3	36.8	38.7	41.9
Marine	20.0	20.5	21.4	22.3	23.3	24.7
Total aquaculture	**49.9**	**52.9**	**55.7**	**59.0**	**62.0**	**66.6**
TOTAL WORLD FISHERIES	**140.7**	**143.1**	**145.8**	**148.1**	**155.7**	**158.0**

Source : FAO, 2014

At the same time, food producing industries of agriculture and aquaculture industry are facing difficulties and rising costs of water, energy, cultivable area, and other resources that are becoming expenses due to demands of urbanization, manufacturing sector, mining and construction industry (Smith *et al.*, 2010, Olaniyi *et al.*, 2013, Wang *et al.*, 2016).

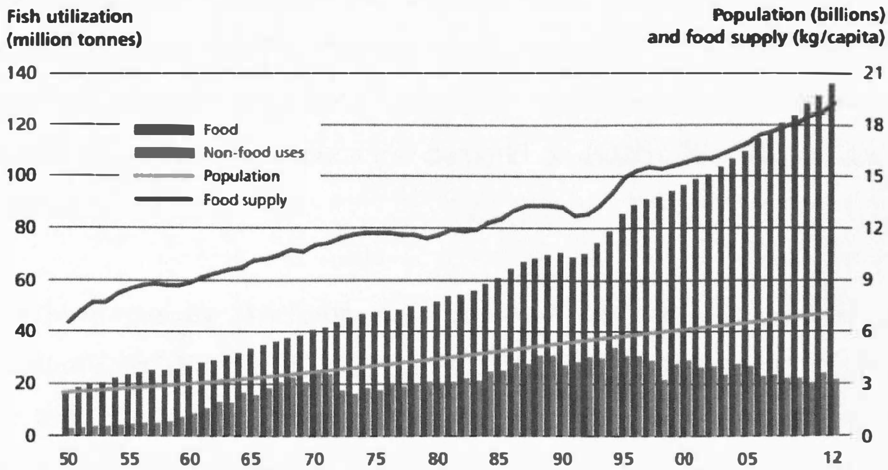

Figure 1.2: World Fish Utilization and Supply

Source : FAO, 2014

In the light of the critical challenges the aquaculture sector must transform to become environment-friendly and socially sustainable. This is necessary to fight malnutrition and hunger (Braun, 2007).

One of the solutions to address these problems is to expand the integrated aquaculture. Integration of aquaculture with conventional agriculture is one of the ways to achieving sustainability in production without many inputs (Mariscal-Lagarda *et al.*, 2012). Technical advances in aquaculture systems need to be improved so that maximum utilization of resources (water, spaces, etc.) is achieved in improving food production. Integrated closed recirculating aquaculture system or named as 'aquaponics' provides the best answers to some of the problems of aquaculture and its impact on the environment.

Aquaponics is an integrated aquaculture system that comprises rearing of both aquatic animals (fish/shellfish farming) and hydroponics (growing plants, especially vegetables, without the presence of soil) in a closed recirculating system (Al-Hafedh *et al.*, 2008; Danaher *et al.*, 2013; Castillo-Castellanos *et al.*, 2015; Hussain *et al.*, 2015; Klemencic and Bulc, 2015; Wahyuningsih *et al.*, 2015; Medina et al., 2016; Nuwansi et al., 2016). This system can provide more than one types of essential nutrition to human beings: source of protein (fish/shellfish culture) and macronutrients, micronutrients and vitamins from vegetables from the integrated hydroponics (Rakocy, 2007). Interest in this method of integrated culture is rapidly catching up due to production efficiency and operation of the system on biodynamic principles that reduce the demand on externalities (Estim and Mustafa, 2010; 2011).

Advantages by practising the aquaponic systems can be seen for water conservation (McMurthy *et al.*, 1997) - less usage of water needed to grow aquatic animals and plants while decreasing the competition for land, space and other resources with other industries (Piedrahita, 2003). It is a concept introduced to replace conventional methods by growing plants in a soilless condition particularly for fruiting and leafy vegetables, flowers and herbs (Blidariu and Grozea, 2011; Love *et al.*, 2015; Tokunaga *et al.*, 2015). Natural fertilizers available in the system are converted from fish waste such as uneaten feed and metabolic by-products that are the main source of nutrients for the plants to grow. This system does not require expensive filters (McMurthy *et al.*, 1997) since it has an inherent filtration system of mechanical filter to filter the solid waste, biological filter that acts as media to convert ammonia to nitrite finally to nitrate in the nitrification process and the main filters in the form of plants which absorb nutrients released into water in the aquaponic system. Aquaponic system produces two different types of food in one single system: protein provided by cultured aquatic animals (fish, prawns, clams and etc.) and minerals, vitamins and fibre from the vegetables (Diver, 2006; Liang and Chien, 2013).

Chapter III discusses the development of three different low-cost aquaponic systems. Three types of aquaponic sub-systems were developed in this study, namely, Media Filled System (MFS), a system where it used media (gravels) for the plant bed. Deep Water Raft System (DWRS), used polystyrene to float plants in a small pot on the top of water and Nutrient Film System (NFS), a method to grown plants in a narrow channels (PVC pipe) where this system allow only a thin film of water continuously flow down followed the gravity. This step-by-step guide describes how to build these three types of aquaponic sub-systems for small-scale aquaculture. Moreover, the materials used and cost of production are also discussed in this chapter.